For office use only
T1 _____
T2 _____
T3 _____
T4 _____

Team Control Number
74641

Problem Chosen
E

For office use only
F1 _____
F2 _____
F3 _____
F4 _____

2018
MCM/ICM
Summary Sheet
(Your team's summary should be included as the first page of your electronic submission.)
Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

Climate Change is Driving the Country More Fragile!

When drought has exacerbated the turmoil in Syria and Yemen, when global warming has threatened the stability of different countries to varying degrees, "how climate change influences the national fragility" has become an urgent problem to be solved.

In this article, we build a fragile state index model to study the direct and indirect influences of climate change on national fragility, and reasonably predict the changes of the fragile states index on the basis of climate change. Furthermore, we also seek the effective state interventions to weaken the hazards of climate change, and calculate the total cost of the interventions.

To start with, it is our task to figure out the influence of climate change on fragility. On the one hand, we select twelve indicators from four aspects: economy, society, nature and politics, and calculate their weights by the Entropy Method, so that our evaluation system of Indicators for Fragile States Index (IFSI) is established. By the method of Set Pair Analysis (SPA) and GE matrix, the fragile states index can be scored both quantitatively and visually. Additionally, we also divide the level of the fragile states index via the Mean-Standard Deviation Method. On the other hand, we select the change quantity of emissions of CO_2, O_3, PM2.5 as the indicators as well as calculate the climate change index for the sake of quantifying climate change. Taking Sudan (one of the top 10 most fragile states ranked by the Fund for Peace) as an example, we can quantitatively analyze the effects of climate change on the fragility of the country.

In the next place, in order to find a tipping point to distinguish whether a country is fragile or not, we use the Neural Network Algorithm as well as the Interpolation Fitting Method to predict climate change, and further forecast the change of national fragility over time. Taking Russia as the research object, we can calculate that it would become a fragile state in 2023.

Then, we find two kinds of state intervention, namely economic intervention and process carbon intervention to reduce the influence of climate change on fragility.

Finally, we discuss the adaptation of the model, and conclude that our model is applicable to larger "states" (such as continents). But when it comes to the smaller "states" (such as cities), the model will fail. In addition, we also put forward the idea of modifying the model.

Keywords: Fragility States Index; Climate change; Entropy Method; Set Pair Analysis; GE matrix; Neural Network

Contents

1 Introduction

1.1 Background

A fragile state is a low-income country characterized by weak state capacity and/or weak state legitimacy. So that the state government is not able to, or chooses not to, provide the basic essentials to its people, leaving citizens vulnerable to a range of shocks.[1]

Climate change is a change in the statistical distribution of weather patterns when that change lasts for an extended period of time. The term "climate change" is often used to refer specifically to anthropogenic climate change. In this sense, especially in the context of environmental policy, the term climate change has become synonymous with anthropogenic global warming.[1]

For a fragile state, the country's population is more vulnerable to the impact of the climate shock. At the same time, climate change also increases a country's fragility. Therefore, it has become an important issue to figure out how climate change influences regional instability.

1.2 Existing Achievements

Achievements on Fragility States Index:

In recent years, the research on fragile states has become a hot issue in promoting national development. And the quantification of fragility is mainly used in fragile states research. As a result, many organizations such as universities and agencies have developed their own evaluation systems of indicators for fragile states index to quantify the fragility. The structural and functional dimensions of some of these evaluation systems are tabulated below.

Table 1: Structural Dimension of the Fragility States Index[2]

Index Name / Structural Dimension	Security	Politics	Economy	Society	Nature
CIFP Vulnerability Index of Carleton University	√	√	√	√	√
Vulnerability Index of the System Peace Research Center	√	√	√	√	
Brookings Frail State Index	√	√	√	√	
The Unstable Book of Conflict in University of Maryland	√	√	√	√	
The Failed National Index of the Peace Foundation	√	√	√	√	
The National Vulnerability Index of the University of George Mason	√	√	√	√	
World Bank CPIA Index	√	√	√	√	
The Political Instability Index of the Economist Intelligence Alliance		√	√	√	
Bertelsmann Foundation's National Weakness Index	√	√			

Table 2: The Functional Dimension of the Fragility States Index[2]

Fragility Index System	Functional Dimension
CRISE Index of University of Oxford	Authority, Service, Legality
CIFP index of Carleton University	Authority, Service, Legality
Research Center of Peace System Fragility Index	Governance, Conflict, Development
George Mason University Vulnerability Index	Validity and Legality

However, there are many drawbacks to the evaluation system above:

- The concept of national fragility is vague and the indicators are subjective.
- The measurement criteria, as well as the transparency surrounding its base data analysis is not available enough.
- The climate change, which has a significant impact on fragility, is not considered.

Achievements on climate change:

The American Anthropological Association (AAA) has released a report called $Cha\text{-}nging\ the\ Atmosphere : Anthropology\ and\ Climate\ Change$ which provides an anthropological research on climate change. From the anthropological point of view, it comes up with 8 main points of understanding the impacts of climate change:

- Climate change is happening
- Climate change exacerbates potential social problems
- Climate change forces human migration to impact cultural heritage
- The impact of climate change is uneven and has a greater impact on the disadvantaged
- Over the last hundred years, the role of human beings on climate change has been great
- Human beings have adaptive systems for environmental changes
- Climate change is a multi-scale comprehensive research problem
- To cope with climate change, it requires not only natural science, but also social science[4]

It can be seen that it is necessary to study the influence of climate change on national fragility.

1.3 Our work

In this paper, we are expected to put forward some disposals to meet two main requirements. For one thing, we are supposed to develop a model that determines a country's fragility and simultaneously measures the impact of climate change as precise

as possible. And for another, in order to draw a convincing conclusion, the model must not only be able to see in what way and when climate change may push it to become more fragile, but has the competence to explain the effect of state driven interventions and predict the total cost of interventions for most countries.

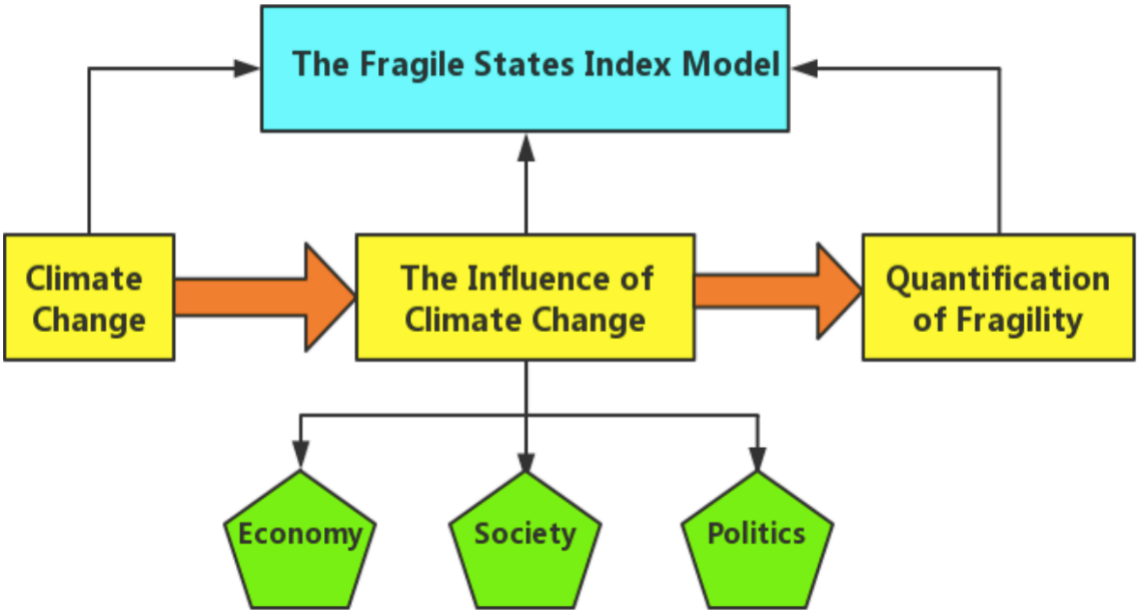

Figure 1: Mind Map

2 The Fragile States Index Model

2.1 Indicators for Fragile States Index

In order to give a well-rounded description of national fragility, a series of indicators is used, which are called Indicators for Fragile States Index (IFSI). According to the existing evaluation systems of IFSI and the principle of reasonableness, we collect four first level indicators, namely economy, society, nature and politics. For each first level indicators, we select three second level indicators. And there is a total of twelve second level indicators. Our IFSI system is shown in Table 3.

Table 3: IFSI System

First Level Indicators	Second Level Indicators
Economy	Gross Domestic Product
	Gross National Income Per Capita
	Final Consumption Expenditure
Society	Quality of Life Index
	Unemployment Rate
	Density of the Population
Nature	Climate Change Index
	CO_2 Emission Index
	Resources
Politics	Crime Rate
	Net Migration Rate
	Strength of Legal rights Index

2.2 Quantification of Fragility

2.2.1 The Entropy Method[3]

In order to study the degree of impact of each indicator on national fragility, the Entropy Method is used. We collect a great deal of data on IFSI from the World Bank, OECD, and internet databases. It is generally believed that the smaller information entropy is, the greater effect of the information value is. Therefore, according to the degree of variation of each indicator, we can use the tool of information entropy to calculate the weight of each indicator. To a great extent, the method can overcome the influence of the subjective judgment of the analytic hierarchy process.

	A	B	C	D	E	F	G
1	Rank	5	36	67	104	142	172
2	Nation	Sudan	Egypt	Russia	Peru	Italy	Ireland
3	Gross National Income	2140	3410	9720	5980	31730	51760
4	Gross Domestic Product	0.95	0.33	1.28	0.19	1.86	0.3
5	Final consumption expenditure	0.76	0.31	0.89	0.15	1.48	0.14
6	Quality of Life Index	99.11	84.42	103.32	100.35	146.13	163.53
7	Unemployment Rate	29.2	24.6	20	15.4	10.8	6.2
8	Population Density	23	96	9	25	206	69
9	Climate Index	84.39	88.45	55.16	97.62	88.26	88.4
10	CO2 Emission Index	0.31	2.376	11.86	1.99	5.27	7.38
11	Resources	4.77	5.09	2.34	7.27	6.19	6.35
12	Crime Rate	63.47	55.88	45.15	68.44	50.18	35.19
13	Net Migration Rate	-589	-275	1017	-240	264	-140
14	Strength of Legal rights Index	3	2	8	8	2	7

Figure 2: Before Standardization

In our model, assume that n indicators and m samples of countries are considered. In following equations, $x_{ij}(x_{ij} > 0)$ represents the original value of indicator i for a sample country j, where $(i = 1, 2, ..., n)$ and $(j = 1, 2, ..., m)$.

Considering that the measurement units of IFSI are not unified, it is necessary to standardize them. In addition, the positive and negative indicators represent different meanings. Therefore, we need to use different method of data normalization:

Positive indicators:

$$x_{ij} = \frac{x_{ij} - \min\{x_{1j}, ..., x_{nj}\}}{\max\{x_{1j}, ..., x_{nj}\} - \min\{x_{1j}, ..., x_{nj}\}}$$

Negative indicators:

$$x_{ij} = \frac{\max\{x_{1j}, ..., x_{nj}\} - x_{ij}}{\max\{x_{1j}, ..., x_{nj}\} - \min\{x_{1j}, ..., x_{nj}\}}$$

For convenience, the normalized data x'_{ij} is still recorded as x_{ij}.

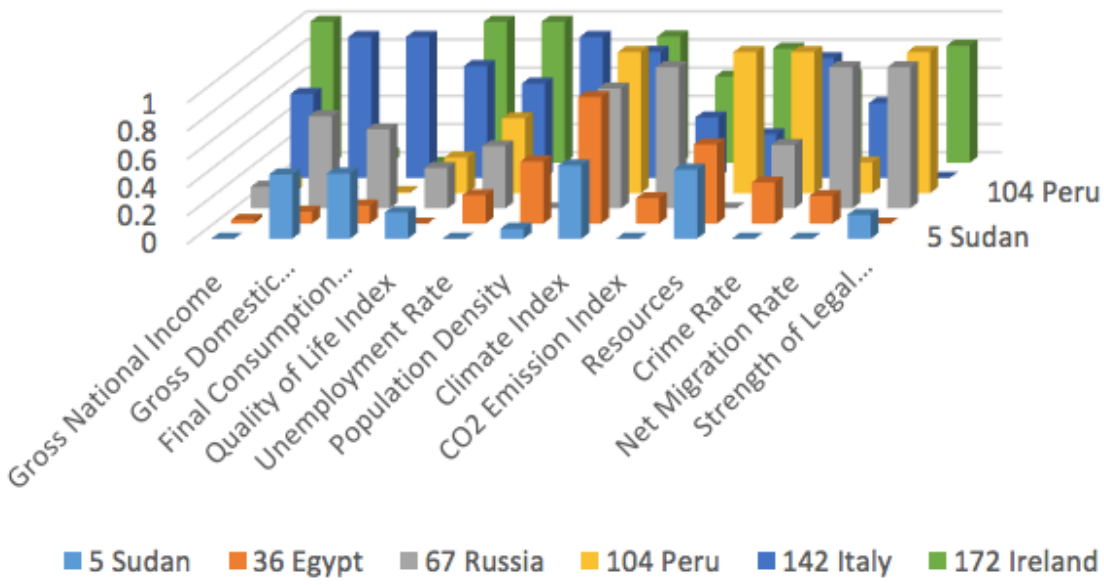

Figure 3: After Standardization

Then calculate the i^{th} sample value of item j accounts for the proportion of the index:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}$$

the entropy of item j is:

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij}$$

$$k = \frac{1}{\ln n} > 0 \qquad e_j \geqslant 0$$

compute information entropy redundancy (difference):

$$d_j = 1 - e_j$$

calculate the weight of the indicators:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}$$

Table 4: Weights of Indicators

Target Level	First Level Indicators	Second Level Indicators	Property of Indicators	Weights(W_j)
Nation(A)	Economy(B_1) (0.4095)	Gross National Income(E_{11})	Sensitivity	0.1293
		Gross Domestic Product(E_{12})		0.1341
		Final consumption expenditure(E_{13})		0.1461
	Society(B_2) (0.1931)	Quality of Life Index(E_{21})	Sensitivity	0.0843
		Unemployment Rate(E_{22})		0.0390
		Population Density(E_{23})		0.0698
	Nature(B_3) (0.1751)	Climate Change Index(E_{31})	Instability	0.1217
		CO_2 Emission Index(E_{32})		0.0497
		Resources(E_{33})		0.0037
	Politics(B_4) (0.2223)	Crime Rate(E_{41})	Instability	0.1566
		Net Migration Rate(E_{42})		0.0446
		Strength of Legal rights Index(E_{43})		0.0211

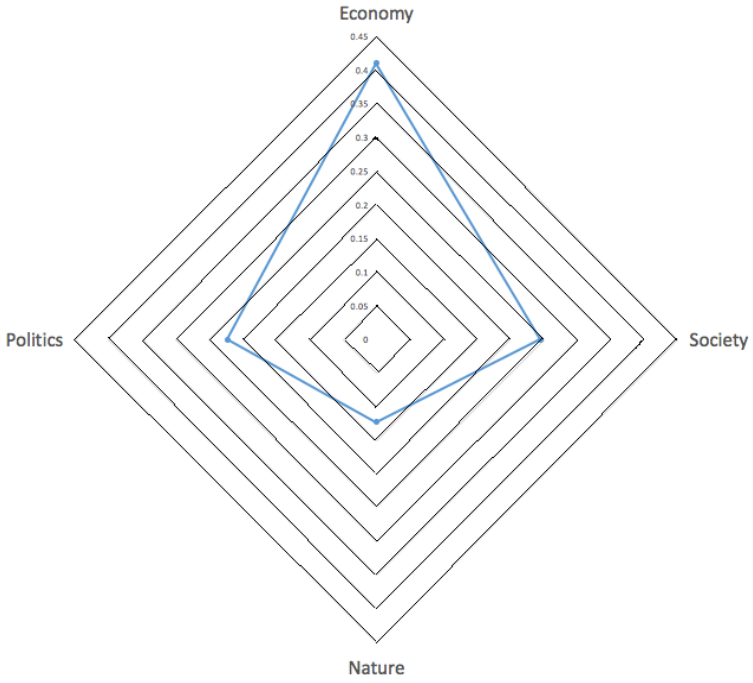

Figure 4:

2.2.2 Set Pair Analysis to Score Fragility[5]

Taking into account the fact that the development of a state shall be confronted with a bunch of unknown challenges, consequently, Set Pair Analysis(SPA) is better recommended to deal with such inconsistent, incomplete and uncertain information, on the top of it, analyze the data inside to figure out implicit knowledge, explaining the underlying laws behind information.[2]

Suppose $Q = \{F, X, E, W\}, F = \{f_1, f_2, ..., f_m\}$ is the evaluation scheme set, $X = \{x_1, x_2, ..., x_n\}$ is the evaluation indicator set, $E = \{e_1, e_2, ..., e_k\}$ is the evaluation object set, $W = \{w_1, w_2, ..., w_n\}$ is the evaluation indicator weight set. Right in the same dimensionality, the comparison of evaluation scheme is used for determining an optimal evaluation set $U = \{u_1, u_2, ..., u_n\}$, and a worst evaluation set $V = \{v_1, v_1, ..., v_n\}$. The link between set F and (U, V) is:

$$\begin{cases} \mu(f_m, U) = a_m + b_m\alpha + c_m\beta \\ a_m = \sum \omega_p a_{pk} \\ c_m = \sum \omega_p c_{pk} \\ p = (1, 2, 3, ..., n) \end{cases} \tag{1}$$

In this equation, a_{pk} is the similarity degree between evaluation index x_{pk} and set $[\nu_p, u_p]$ and c_{pk} is the opposition degree between x_{pk} and $[\nu_p, u_p]$, besides, w_p is the p^{th} weight.

When x_{pk} has a positive effect on the evaluation results:

$$\begin{cases} a_{pk} = \frac{x_{pk}}{u_p + \nu_p} \\ c_{pk} = \frac{u_p \nu_p}{x_{pk}(u_p + \nu_p)} \end{cases} \tag{2}$$

When x_{pk} has a negative effect on the evaluation results:

$$\begin{cases} a_{pk} = \frac{u_p \nu_p}{x_{pk}(u_p + \nu_p)} \\ c_{pk} = \frac{x_{pk}}{u_p + \nu_p} \end{cases} \tag{3}$$

Relative correlation set r_m between scheme p_m and the optimal evaluation scheme set U is defined as:

$$r_m = \frac{a_m}{a_m + c_m}$$

Among the definition, r_m reflects the correlation degree between the evaluation scheme f_m and the optimal scheme set U. The bigger the value of r_m is, the closer to optimal scheme the evaluated objects are. Thus, r_m can be used as Fragile States Index.

Mean-Standard Deviation Method to divide national fragility level:

According to the data in Figure 3 and the method of SPA, we can score the Fragile States Index for Sudan, Egypt, Russia, Peru, Italy and Ireland. And then, it is easy to

calculate the mean index (μ) and the standard deviation (std). By the means of Mean-Standard Deviation Method, all of the indexes can be classified into three levels: fragile $(0 \leqslant r_m < \mu - std)$, vulnerable $(\mu - std \leqslant r_m < \mu + std)$, and stable $(\mu + std \leqslant r_m < 1)$.

It comes to a result that among fragile countries and vulnerable countries, the boundary index is 0.30769, among vulnerable countries and stable countries, the boundary index is 0.76923. The score breakdown is as follows:

Table 5: National Fragility Classification

National Fragility Level	Level 1	Level 2	Level 3
	Fragile	Vulnerable	Stable
Fragile Index(r_m)	$0 \leqslant r_m < 0.3077$	$0.3077 \leqslant r_m < 0.7692$	$0.7692 \leqslant r_m < 1.0$

2.2.3 GE Matrix to Quantify Fragility

In our model, the national fragility is a concept which contains both sensitivity and instability. Sensitivity refers to the degree of impact of external or internal factors such as climate change. And instability reflects the economic and social development capacity of a country. Therefore, in order to take a comprehensive measurement of the fragile states index, a Sensitivity Index (SI) and an Instability Index (II) are introduced into our evaluation system. Political Indicators and Environmental Indicators are classified as SI, while Economic Indicators and Social Indicators belong to II.

Both evaluation indicator set $X = \{x_1, ..., x_n\}$ and evaluation indicator weight set $W = \{w_1, ..., w_n\}$ are divided into two parts: instability index set $X_I = \{x_{I1}, ...x_{I\lambda}\}$ and sensitivity index set $X_S = \{x_{S\lambda}, ..., x_n\}$, the evaluation indicator weight set W is the same.

First of all, we define

$$w'_{Sk} = \frac{w_{Sk}}{\sum_{i=\lambda}^{n} w_{Si}} \qquad w'_{Ik} = \frac{w_{Ik}}{\sum_{i=1}^{\lambda} w_{Ii}}$$

The Sensitivity Index (SI) is defined as:

$$SI = \begin{pmatrix} w'_{S\lambda} \\ w'_{S\lambda+1} \\ . \\ . \\ w'_{Sn} \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} x_{S\lambda} \\ x_{S\lambda+1} \\ . \\ . \\ x_{Sn} \end{pmatrix} \tag{4}$$

The Instability Index(II) is defined as:

$$II = \begin{pmatrix} w'_{I1} \\ w'_{I2} \\ . \\ . \\ w'_{I\lambda} \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} x_{I1} \\ x_{I2} \\ . \\ . \\ x_{I\lambda} \end{pmatrix} \tag{5}$$

For the sake of visualizing the national fragility, a GE Matrix (Figure 5) is adopted. The GE Matrix can be used to evaluate institutions based on their market strength and their market attractiveness. The current business (or institution) is evaluated according to the attractiveness index and the strength index.

Here we can also consider a GE Matrix to evaluate the national fragility through analogy. Two properties of index (SI and II) are used to evaluate fragile states index. Both SI and II can also be classified into three levels as shown in Table 6.

Table 6: Classification of SI and II

National Fragility Level	Level 1	Level 2	Level 3
	Fragile	Vulnerable	Stable
SI	$[0,\ 0.3077)$	$[0.3077,\ 0.7692)$	$[0.7692,\ 1)$
II	$[0,\ 0.3077)$	$[0.3077,\ 0.7692)$	$[0.7692,\ 1)$

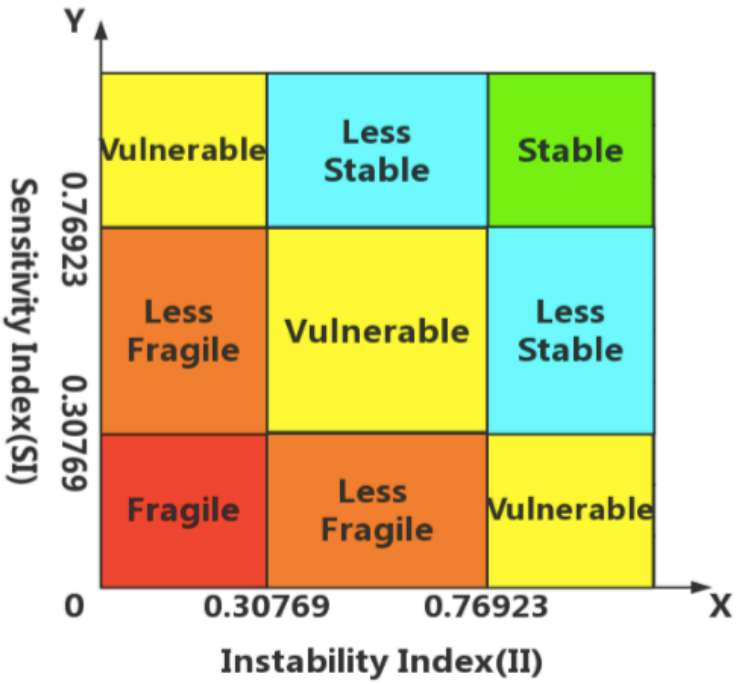

Figure 5: A GE Matrix to Evaluate SI and II

From the GE matrix we can directly read the national fragility. What's more, the GE matrix can also be used to calculate the Fragile States Index as the distance to $(0,\ 0)$:

$$Distance = \sqrt{SI^2 + II^2}$$

Distance can measure the fragility of a country. The smaller the distance is, the more fragile the country is.

3 The Influence of Climate Change on Fragility

A 2015 study, commissioned by the G7 member states, identifies seven climate-fragility risks that pose threats to the stability of states and societies in the decades ahead. It suggests that dynamics of state fragility, social and political fragility, may be exacerbated by climate change impacts and that the consequence of this is reduced adaptation capacity. Thus, it is our work to understand how climate change influence the national fragility via the method of mathematical modeling.

Our thinking progress is illustrated by a fishbone diagram (Figure 6), which is widely used in finding the root cause of the problem and analyzing the factors that affects the problem.

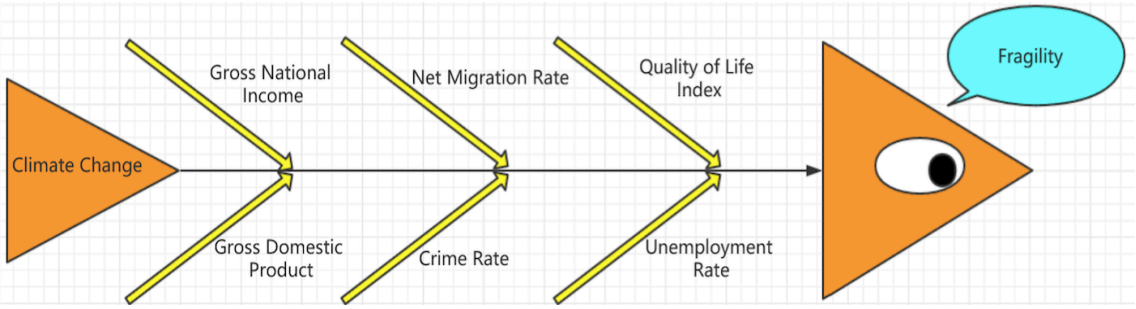

Figure 6: Thinking Process Finishbone

3.1 Quantification of Climate Change

For the purpose of understanding the influence of climate change on fragility scientifically, we need to quantify the climate change. Here in our model, climate change refers to global warming. And it is universally acknowledged that the pivotal cause of the global warming is the greenhouse effect. Thence we select the change quantity in emissions of CO_2 (the main greenhouse gas), O_3 (the gas that can reflect the solar radiation), and PM2.5 (the gas which has a great impact on the greenhouse effect and air quality) as the indicators for climate change.

We assume that the change quantity of emission of the index are C_{CO_2}, C_{O_3}, and $C_{PM2.5}$. Additionally, their weights w_{CO_2}, w_{O_3}, and $w_{PM2.5}$.

Then, the climate change index(x_{CHI}) can be defined as:

$$x_{CHI} = C_{CO_2} w_{CO_2} + C_{O_3} w_{O_3} + C_{PM2.5} w_{PM2.5}$$

Besides, in order to increase the accuracy and objectivity of the calculation of x_{CHI}, we still use the Entropy Method rather than bestowing weighing subjectively to get the weights of CO_2, O_3 and PM2.5.

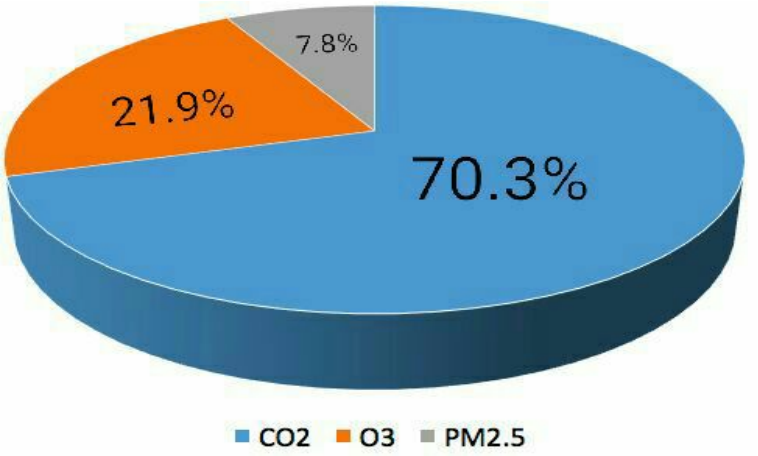

Figure 7: Weights of Climate Change Indicators

3.2 Direct Influence on Fragility

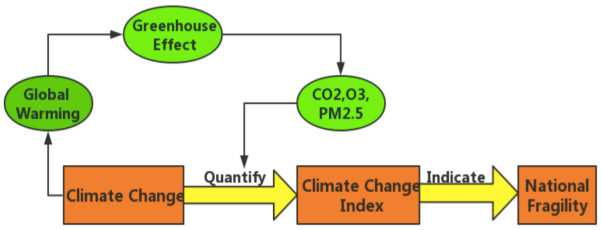

Figure 8: Direct Influence on Fragility

The quantitative result of climate change is the climate change index (3.1), while the climate change index is one of the indicator of the national fragility (Table 4). As a consequence, climate change increases fragility through direct means.

3.3 Indirect Influence on Fragility

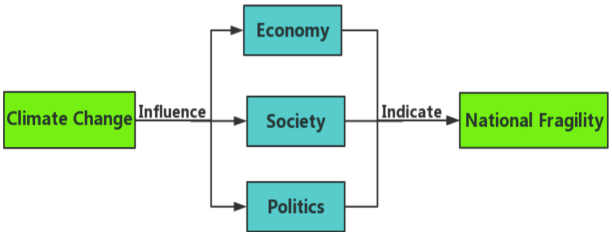

Figure 9: Indirect Influence on Fragility

Influence on Economy: The change of production volume is constrained by climate change factors. The price fluctuation and quantity change of market products caused by climate change finally lead to the market downturn. Adverse climate change can result in loss of direct utility, loss of ecosystem services, and loss of biodiversity.

Influence on Politics: The development of individuals and nation can't survive without carbon emissions. No one wants to limit their development in order to reduce carbon emissions, which will eventually lead to tension in the domestic and international situation.

Influence on Society: After consulting a large number of annual average GHG growth and previous investments in natural disaster prevention and the losses caused by climate change, we get an average data: The average cost of social carbon is estimated at $43 per ton of carbon dioxide[6].

3.4 Case Study: Sudan

Aimed at understanding how climate change may increase fragility of a certain country, Republic of the Sudan is chosen as a sample. Sudan is chosen as the subject of the the influence of climate change on national fragility for a few reasons:

- Sudan is listed one of the top 10 most fragile states released by the Fund for Peace. Moreover, Sudan ranked 5 with a fragile states index of 110.6 in 2017.
- A complete data set was available for Sudan, which allows for an accurate calculation of the Fragile States Index in our own model.
- Sudan's single economic structure has caused the country to be greatly influenced by climate change. In this case, it makes sense to study how climate change influence Sudan's national fragility.

The north and South Division marks a new and significant change in the peace process of Sudan that has lasted for more than half a century. But South Sudan, once separated, would mean the loss of Sultan's "largest country in Africa", and lost counts of wealth. In history, the South and North Sudan separate more and belong to different civilizations. The independent referendum will inevitably have a great impact on cultural exchange.

Walking to this step shows that the cracks between the various ethnic groups in Sudan have reached a very deep level. The estrangement has profound historical and realistic reasons. It is not easy to make up for one thing or another. To eliminate this centrifugal force, Sudan has a long way to go.

There is no doubt that the fragility of Sudan is increasing.

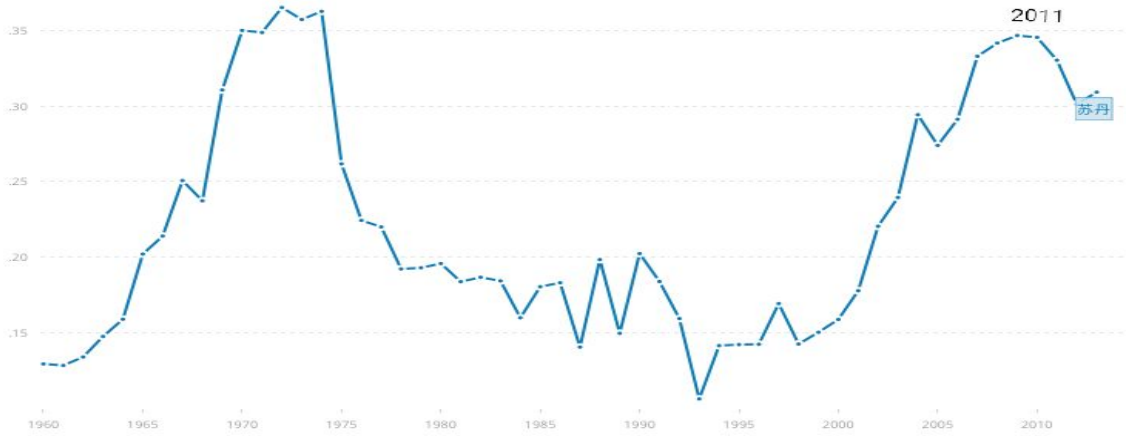

Figure 10: CO_2 Emission of Sudan

We collected the data of two years before and after 2011, found that the CO_2 index and PM2.5 index reached a peak in 2011 among recent years, in order to further illustration, we put the data into the formula, the fragility index of Sudan in 2011 decreased by 0.0029, indicating the fragility of Sudan increased sharply because of climate change. This also reflects Sudan's independent referendum in 2011.

4 Fragile States Index Forecasting Model

Given that Fragile States Index plays a key role in the stability and development of a country, it is necessary to predict the change of national fragility. The predictions are expected to contain that: In what way and when a country will be more fragile; When a country may reach the tipping point that can distinguish the national fragility between stable and fragile.

4.1 Assumptions

To make the predictions of the Fragile States Index more accurate, the following assumptions are made in this forecasting model:

- In this model, all the factors except climate change are considered as constant in predicting when a country will reach the tipping point. Consequently, the change of national fragility is only related to climate change over time.

For a national system, when it is in a time-only condition, the economic, social and political indicators will not take the initiative to break the steady state. While the climate change may have a great impact on these indicators via the effects like droughts, shrinking glaciers, changing animal and plant ranges, and sea level rise. Based on the above, the assumption is reasonable.

- In order to make the model equipped with universality, which means it can be widely used in Asia, Africa, North America and other regions, the impacts of climate change are supposed to be considered globally consistent.

4.2 Forecast of the Fragile States Index

In accordance with the assumptions above, we are able to predict the change of national fragility through projections of climate change. Besides, the climate change can be quantified (3.1).

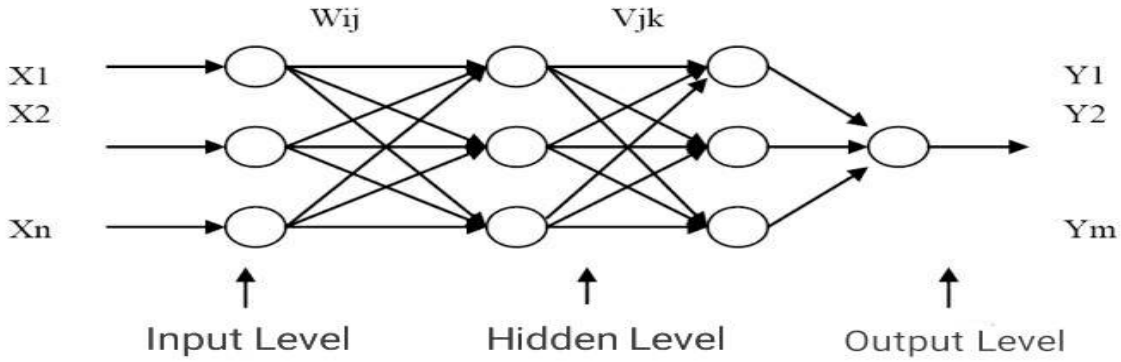

Figure 11: Theory of BP Neural Network

BP (Back Propagation) Neural Network is a multi-layer feedforward network trained by error inverse propagation algorithm, which is one of the most widely used neural network models. And the BP Neural Network's ability of classifying any complicated pattern and its excellent multi-dimensional function mapping capabilities make it a better solution to predict future climate change.

So that by the method of BP Neural Network Algorithm, and taking the time as a variable, a reasonable estimation of the future climate change can be obtained according to the data from 2001 to 2017. Furthermore, when a country will reach the tipping point can also be predicted more precise.

4.3 Case Study: Russia

Randomly, Russia is selected as a country that out of the top 10 fragile state ranked by the Fund for Peace, and this forecasting model is supposed to predict when Russia may reach the tipping point.

To start with, we collect the data from 2001 to 2015, which contains the emissions of CO_2, O_3 and PM2.5. The next step is to train the Neural Network(Figure 11, 12, 13). After that, a BP Neural Network model is set up as follows:

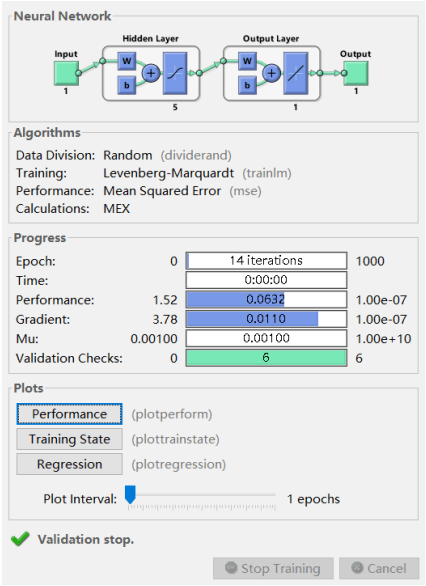

Figure 12: Neural Network Training(1)

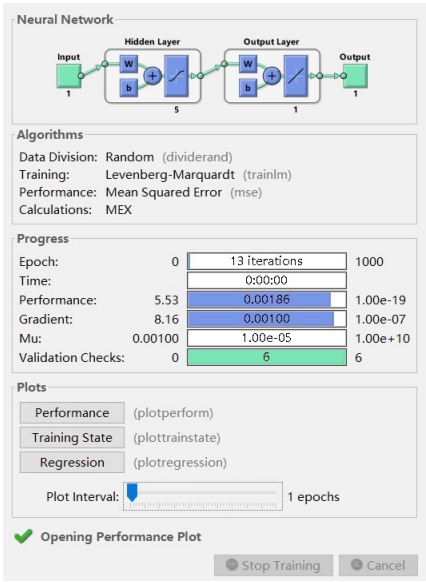

Figure 13: Neural Network Training(2)

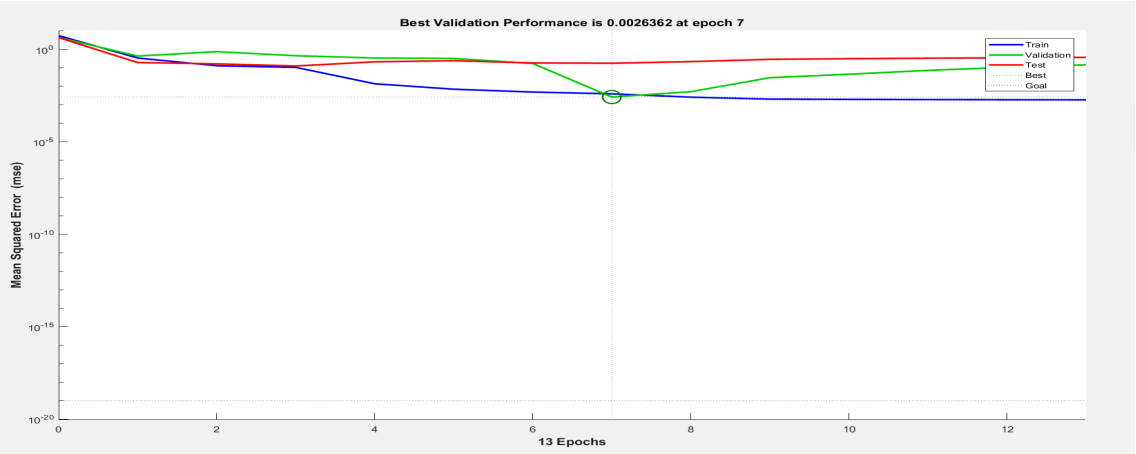

Figure 14: Training Efficiency of Neural Network

In order to further the reliability of prediction results of BP neural network, we use interpolation fitting method to curve the past and future data, comparing with the form of chart, discarding the apparent error part, and the following is the final prediction curve. After that, a equation about C_{CHI} is obtained and then predict curves of CO_2, O_3 and PM2.5 can be drown(Figure 15, 16, 17).

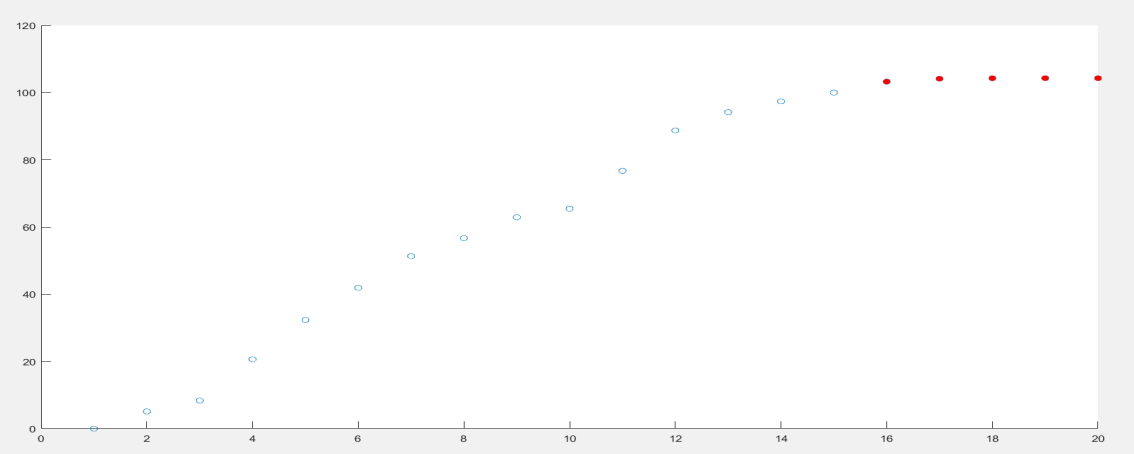

Figure 15: Partial Prediction Results

Before fitting the curves, due to the fact that the relation among climate change and its relative factors $(CO_2,\ O_3,\ PM2.5)$ have not been verified by professional theory, we can only through their previous data to analyze their correlations, the model audaciously put forward a hypothesis that the indexes(CO_2 O_3, PM2.5) with time variable are for the polynomial variable values.

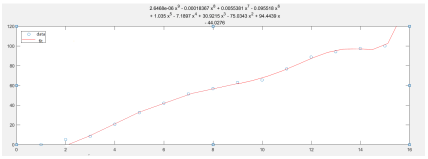

Figure 16: Fitting CO_2 Curve

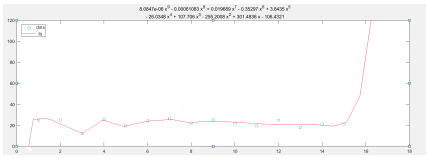

Figure 17: Fitting O_3 Curve

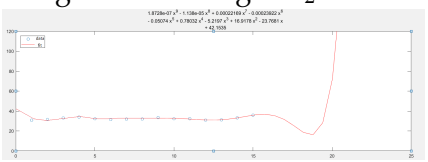

Figure 18: Fitting PM2.5 Curve

$$C_{CHI} = 0.0000043x^9 - 0.0003146x^8 + 0.0098043x^7 - 0.1724728x^6 + 1.8664701x^5 - 12.7526189x^4 + 53.5614693x^3 - 127.9718954x^2 + 155.6998733x - 4.2919612$$

Finally, we calculate three real solutions and six virtual solutions by solving the equation. Taking into account the realistic constraints, we discard real solutions under 18 and all the virtual solutions.

Consequently, we get a valid solution, that is, Russia may reach the fragile state in 2023 (Details on Figure 18).

```
Solve(0.0000043x^9-0.0003146x^8+0.0098043x^7-0.1724728x^6+1.8664701x^5-12.7526189x^4+53.5614693x^3-
127.9718954x^2+155.6998733x-4.2919612=0.3177/0.1217)
```

[8.725194529104, 23.280446456969, 12.00727384899 - 7.728805448333i, 12.00727384899 + 7.728805448333i, 2.16244511214 + 2.496326250632i, 6.385835387869 - 6.032542477065i, 2.16244511214 - 2.496326250632i, 6.385835387869 + 6.032542477065i, 0.046041013603]

Figure 19: Solution of the Equation

5 State Driven Interventions to Reduce Fragility

5.1 Two Means of State Intervention

We believe that a state can use two interventions to reduce the impact of climate change on national fragility, which are:

- Intervention aiming at improving economic, social and political indices.

Economy, society, nature and politics indicators are first - level indicators to measure the fragile states index. Through the state intervention, we can improve the economy, society and politics index of the country to compensate for the decline of the nature index caused by climate change, so as to avoid the improvement of the national fragility.

From the radar chart (Figure 4), it is known that for a country, economy indicators are the most important among the indicators that affect its fragility index. Therefore, for a country that is getting the tipping point of fragility index, the national intervention it needs most is economic intervention. Basically, the increase of social index and political index still depends on the increase of economic index. Therefore, this means of intervention is essentially economic intervention.

- Intervention to deal with climate change directly.

And the solution is to reduce the greenhouse effcet and the climate change index via a low carbon development model.

5.2 Costs of State Intervention

Reducing the fragility of our country is the hope of all people, but it may cost a lot to mitigate and get rid of the risk of climate change through state driven interventions.

First of all, the cost can be divided into the cost of human resources and cost, that is to say, to help countries improve the fragility index, which can provide personnel to help the country to complete the construction of infrastructure, and it can also provide food, water and other means of production. However, concerning the feasibility and computability of the calculation process and the accuracy of the results, when measuring the cost of state intervention, the total cost of intervention is represented by the cost.

Next, we will calculate the costs of the two interventions.

5.2.1 Cost of Economic Intervention

According to the relative weight of economy and climate change in the national fragility index, for a determined country, it is considered that the decline of the national fragility index caused by climate change can be compensated by the increase of the economy index. In order to quantify the cost of intervention, the economy index can be represented by M_2(Broad Money), and the intervention cost is the increment of the value of M_2.

5.2.2 Cost of Carbon Processing

Through the increment of the national fragility index before and after the intervention, if other indices except the climate change index remain unchanged, the increment of the national fragility index is just the increment of the climate change index. At the same time, the climate change index is the weighted quantitative result of CO_2, O_3 and PM2.5. And the weight of CO_2 occupies the most, therefore, the decrease of CO_2 can be calculated by the increment of the climate change index. Using the formula:

$$Cost = CO_2\ reduction\ (T)\ \times\ cost\ of\ process\ per\ ton\ CO_2$$

And the final cost Russia may pay for getting rid of a fragile state is around $507551167.

6 Adaptability and Improvement of the Model

6.1 Adaptability of the Model

In terms of the measurement of national fragility and the factors which influence fragility, we can find that climate change is undoubtedly an important variable. What's more, the climate change index is calculated by the data of "an ideal country", which refers to the average of the whole world in our model.

While evaluating the change of fragile states index of a country, we only need to put the data directly into the model and then calculate it. That is to say, when the whole world is the object of research, the accuracy of our model is the best. But when the scope of objects become narrower, the accuracy will reduce.

Therefore, we can reach the conclusion that: when the model is used in larger "states" (such as continents), the results are consistent with expectations; but when the model is used in smaller "states" (such as cities), the fragile states index of each city of a country will be highly similar. In this case, the model won?t work.

6.2 Improvement of the Model

In order to solve the problem that the model is not suitable for smaller ?states? (such as cities), we should analyze the local differences in climate change as well as the change of other factors specifically.

Thus, we could put forward two methods of improvement of the model:

- The Method of Cellular Automata[7]

In this improved model, we define city as Cell, the whole country as Lattice, the adjacent cities as Neighbor. And according to the change and relationship of the indicators for fragile states index, as well as taking the local differences into consideration, we can make the Rule, which can be written as:

$$S_i(t+1) = f(S_{i-r},\ S_{i-r+1},\ ...,\ S_i,\ ...,\ S_{i+r-1},\ S_{i+r})$$

So that we can develop a model of social system based on Cellular Automata to study the fragility of cities under different circumstances accurately.

- The Method of Simulation in Ecology[8]

By the usage of Sella, a system dynamics software widely adopted in the Simulation in Ecology, we can simulate how climate change influences the system visually.

References

[1] https://en.wikipedia.org/wiki

[2] Tianxu Liu, Tao Wu, *Evaluation Criteria of Fragile States*, Licai Taolun, 2016.

[3] Guifang Li,Dongdong, Ma, Jun Xu East China Economic Management, 2017

[4] American Anthropological Association, *Changing the Atmosphere : Anthropology and Climate Change* 2015

[5] Keqing Zhao, *Set Pair Analysis and Its Application*[M], Hangzhou, Zhejiang Technology Publication, 2000

[6] Zhou Peng, Zhou Xun, Zhou Dequn, *A Survey of Studies on Estimating CO_2 Mitigation Cost* 2017

[7] Li yanling, *The Simulation Model of Complex Social System Based on Cellular Automata* 2007

[8] Pengwei Ming, Shouxing Song, *Modeling and Simulation of Urban Vulnerability under Climate Cha* University of Transportation 2014

[9] https://data.worldbank.org.cn/indicator?tab=featured

[10] http://www.globalchange.ac.cn/index.jsp

[11] https://www.ncdc.noaa.gov/sotc/global/201713

[12] http://www.oecdchina.org/search.html